Design of Agroforestry systems with coffee is facilitated by the description of relationships between Ecosystem Services provided

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1 Introduction

Ecosystem services (ES) have been defined as "conditions and process whereby the ecosystem sustains the primary human needs" (Daily, 1997). Cropping system do not provide only agricultural products, but also a range of services and disservices to the society. A way to achieve agroecological intensification of cropping systems could be reached by optimizing the ES they provide (Doré, 2011). Our study focused on coffee agroforestry systems that are supposed to provide a bigger ES panel in comparison with monospecific cropping systems (De Beenhouwer, 2013). The specific and structural complexity of these systems makes this optimization a methodological challenge. Our aim was to propose pathways for an agroecological intensification of theses cropping systems by studying the determinants of the provision of ES and the relationships between them. Four ES have been considered, coffee production, tree biodiversity, carbon sequestration into the aboveground biomass and quality of output water from coffee agroecosystems. We bore a specific interest to coffee production because economically is the most important service for growers, the 3 other services being more environmental and thus important for the cropping system sustainability but not for producer livelihoods. Several steps were necessary in order to reach the objectives: (i) understanding and quantifying ES determinants (ii) assessing the links between ES (independence, facilitation or trade-off) (iii) identifying cropping systems and innovating cropping practices that optimized the delivery of these four ES.

2 Materials and Methods

The study was done in Nicaragua, municipality of Tuma-La Dalia, 40 km north of the regional capital Matagalpa. A first survey was carried on 82 coffee producers selected by snowball sampling from April to June 2014. It enabled the determination of services related to water quality and coffee production at farm scale (by interview) and to tree biodiversity and carbon sequestration measured in a 20x50 m^2 plot in a representative coffee plantation. To better assess the determinant of coffee production, a second survey was led with 27 farmers, part of the 82 initial sample, from July to October 2014: we measured the main state variables of the system in 3 repetitions in the 20x50 m^2 plot and led thorough interviews about cropping practices with the producers.
The service of Water Quality - WQ - (score without unity) has been constructed based on doses of active ingredients of pesticides applied, and from the active molecule properties of the pesticides (IUPAC, the Pesticide Properties DataBase – PPDB – 2013). Tree biodiversity - Sh - (without unity) and carbon sequestration - C seq - (t of C) services have been applied for the shade trees of the agroforestry systems and calculated respectively with the index of Shannon (1948) and with an allometric equation from Chave et al. (2005). The service of coffee yield ($kg.ha^{-1}$) has been first picked up from the interview (data for 2013) and then field estimated (2014).

3 Results – Discussion

There was no connection between tree biodiversity and carbon sequestration (Fig. 1). Carbon sequestration was much more strongly related to tree diameter -and, to a lesser extent, to wood density- than to the number of trees. We found weak but significant correlation between coffee yield and water quality (negative, p-value = 0.015) (Fig. 2). The more pesticides are applied, the higher is coffee yield. But yield was not correlated with tree biodiversity nor with carbon sequestration (Fig. 2). Agronomic diagnosis enabled to know that coffee yield was highly and negatively correlated to shade density, to fongal disease and to weed pressure and positively correlated to soil pH.
Based on the quantification of the four ES, we separated by cluster analysis two types: one, smaller -9 coffee plantation among the 27- where high quantities of ES were provided, and the other one –the 18 coffee plantation remaining where provision was lower (Table 1). The mean values obtained for the 9 selected growers can be used as goals to reach for agroecological intensification. Disease, soil pH and nitrogen are statistically different, and also shade and weeds of the agroforestry coffee based system. To reduce shade, more time for pruning shade tress will be necessary. This would allow a faster weed development, and thus to mitigate it, producers will have to increase density of coffee plantation or

spend more time for mechanical weeding. To minimize weeds and fungal disease, the use of environmental friendly and efficient pesticide (identified during our study) could be a solution. Soil nitrogen and pH are important for coffee production and are as well correlated with the density of leguminous tree. Many Fabaceae trees contribute to maintaining a good level of soil Nitrogen but at the same time acidify the soil (Moura, 2015). Therefore to optimize the soil parameters it is necessary to find a good leguminous density, around 50 trees.ha^{-1}. Besides biodiversity seems to have a role to obtain this high joint provision of ES, except water quality service, and a more regular renewal of coffee plantation should allow better production.

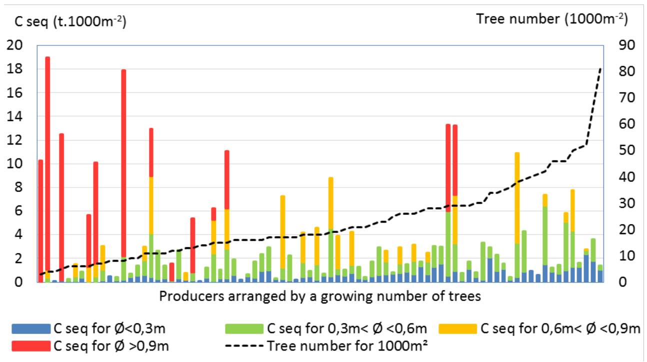

Fig. 1. Example of C seq to understand the determinants for the provision of this service. Ø means tree diameter.

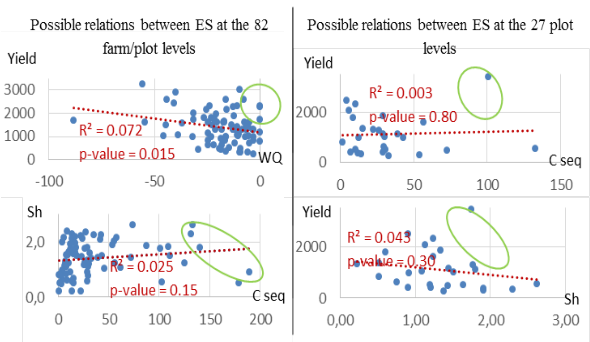

Fig. 2. Feasible relations between ES with the correlation coefficient (R-squared) and the p-value indicating the curve significance. Green ellipses shows where we should find trade-offs or win-win situations.

	Comparison element	Means of the 9 producers selected	Means of the other 18 producers	T-test
ES	Coffee yield(kg.ha^{-1})	2318 ±602	774 ±412	*
	WQ (index)	45.4 ±4.7	39.5 ±11.3	*
	C seq (t.ha^{-1})	40.4 ±45.6	27.8 ±19.1	
	Sh (index)	1.47 ±0.69	1.22 ±0.47	
State variables of agroforestry systems	Disease (% affected leaves)	0.08 ±0.13	0.30 ±0.34	***
	Shade (% plot covered by tree shade)	41.4 ±15.2	52 ±11.7	*
	Weeds (% ground plot covered)	21 ±14.6	30.4 ±16.2	*
	pH	6.23 ±0.44	5.79 ±0.25	***
	N soil (mg/L of nitrogen in the soil)	0.31 ±0.06	0.22 ±0.09	***
	Organic matter (% soil)	4.74 ±0.55	4.53 ±0.77	
Managing practices and shade tree choices	Nitrogen fertilization (kg.ha^{-1})	44.4 ±48.1	26.9 ±40.1	
	Pruning time of shade trees (days.ha^{-1})	4.1 ±3.1	5.1 ±3.8	
	Number of tree species (/1000m²)	9.5 ±6.1	5.9 ±2.7	*
	Number of fruit trees (/ha)	260 ±210	150 ±160	
	Number of firewood/timber trees (/ha)	70 ±25	50 ±70	
	Number of Fabaceae trees (/ha)	50 ±70	140 ±90	***
	Coffee age	8.4 ±5.1	14.6 ±13.6	*
	Density of coffee plantation	4940 ±1425	4720 ±1233	

Table 1. Comparisons of ES values, state variables of agroforestry systems and managing practices means between a group of 9 producers with high ES provision and the others (group of 18 producers). Student test was running to bring out the significant differences. Code signification, p-value: <0.05 "***", <0.15 "*"

4 Conclusion

This method permit to provide some pathways for designing agroforestry system in accordance with agroecological intensification trying to optimize the provision of several ES. We identified the action leverage, in other words state variables and managing practices to change in the coffee based agroforestry. However, we did not assess the feasibility for the producer to implement those modifications that would probably take more time than conventional management.

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